Phase-shifting cell loaded with variable capacitances for dual linearly polarized reflectarrays

Tony Makdissy, Raphaël Gillard, Erwan Fourn, Etienne Girard, Hervé Legay

Phase-Shifting Cell Loaded with Variable Capacitances for Dual Linearly Polarized Reflectarrays

T. Makdissy, R. Gillard, E. Fourn, E. Girard and H. Legay

A new dual linearly polarized phase-shifting cell for reflectarray applications is presented. It consists of two orthogonal sets of parallel rectangular slots etched in a ground plane. Each set may be loaded with a combination of variable and fixed capacitances to provide a reconfigurable 2-bit phase-shifter for both polarizations. A passive version of the proposed cell has been fabricated and characterized in C-band with four fixed states. For each polarization only two variable capacitances are needed in order to control the phase of the reflected wave.

Introduction: Reflectarray cells usually use patches or slots to vary the reflected phase. When multiple resonators are used in the same cell, the phase range coverage is increased [1, 2]. Multiple resonators on a single layer structure are preferable as it results in a simpler technological process. For reconfigurable cells, the number of active elements in a cell should be relatively low in order to preserve a low-cost antenna. In a previous work [3] we have proposed a single linearly polarized phase-shifting cell which consists of three rectangular slots etched in a ground plane. This cell uses only one variable capacitance in order to control the phase of the reflected wave. Measurements have demonstrated a 2-bit phase-shifter over 7.4% of bandwidth. A dual polarization unit cell was also proposed in [4], a nearly 2-bit phase-shifter is provided over a bandwidth of 5.1%. In this letter, a new type of phase-shifting cell for dual linearly polarized reflectarrays is proposed. It is inspired from the triple-slot topology as it uses multiple resonators (rectangular slots) on a single layer substrate with a convenient capacitive loading.

Proposed phase-shifting cell: The proposed cell is illustrated in Fig. 1. It consists of two orthogonal sets of parallel rectangular slots etched in a square ground plane. The vertical slots are used for the horizontal polarization and vice versa. For each polarization, two different slot lengths are combined to improve the bandwidth. The ground plane is printed on a 1.6 mm substrate with 2.17 dielectric constant, suspended 15.7mm above a square metallic cavity. The principle of this structure is to control the reflected phase of each polarization independently with the capacitances (v) loading the smallest slots. This capacitance is obtained in the gap between the electrode and the metallic wall of the cavity. Its value can be tuned by choosing the length (L) of the electrode. For each polarization, four different phase states are obtained. Each state is labelled (Dx), where D is replaced by V for vertical polarization or H for horizontal polarization and x is replaced with an integer from 0 to 3 representing the configuration's number. As the two polarizations are independent, the reflected phase of configuration Vx is not modified when configuration Hy changes. The largest slots are used to achieve a smooth phase evolution; their resonant frequency has to be optimized. Here, this is done by loading them with a fixed capacitance (f). This capacitance increases the electrical length of the slots with no need to bend them or to raise cell size.

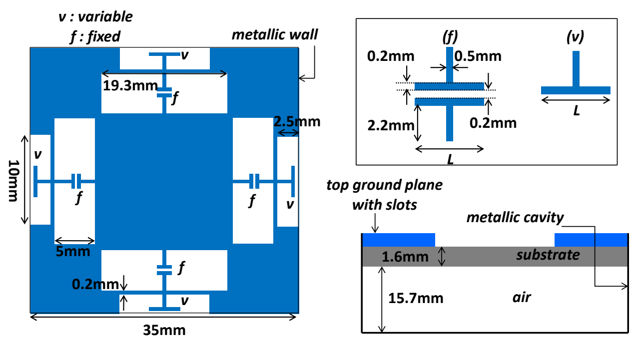
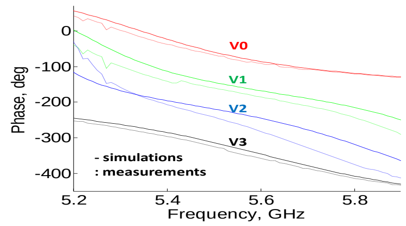
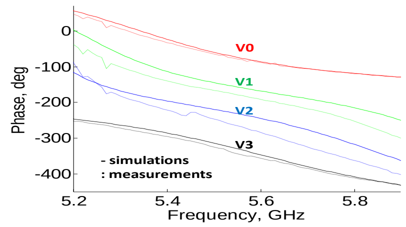


Fig. 1 *Proposed phase-shifting cell.*

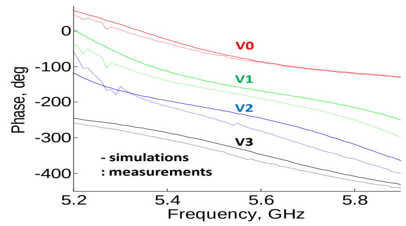
Simulation and experimental results: The performances of the proposed topology have been assessed at 5.35GHz. Numerical characterizations with HFSS® have been carried out using the waveguide simulator approach by placing the cell at the end of a 35*35mm^2 square metallic waveguide. The cell is excited with the TE_{10} mode with electric field perpendicular to the horizontal slots. The electrode's length (L) of the capacitances (f) is 1mm. The four suitable values of the electrode's length (L) of the capacitances (v) are {0.8mm, 2.95mm, 3.75mm, 5.5mm} corresponding to the configuration's numbers {0, 1, 2, 3}. For these values, four uniformly distributed phase states are obtained whatever the orthogonal state. A total of 16 different configurations are obtained when combining both polarizations. The simulated and measured reflected phases are given in Fig. 2. The agreement between both is very good. It shows that the reflected phase of configuration Vx is not modified when configuration Hy changes. Fig. 3 illustrates the measured phase standard deviation of the vertical polarization for the four horizontal states. Its stability reflects the parallelism between the curves. The ideal value is 26° for a 2-bit phase-shifter [3]. Here, it is better than 31° in the useful band from 5.24GHz to 5.8GHz, corresponding to a 1.74-bit phase-shifter. As the cell uses multiple resonators for each polarization, the bandwidth is improved compared to previous solutions (10% here instead of 5% in [4]). The maximum measured losses are less than 1 dB in the useful band as illustrates Fig. 4. In a future active version, the gap capacitance could be replaced either by capacitive MEMS [5] or by *varicap* diode [6]. Indeed, as shown in [5] for single polarization, the proposed topology is also fully compatible with a continuous variation of the capacitive loading. This is a real advantage compared to [4] where *pin* diodes are used as switches to provide a limited number of discrete phase states.



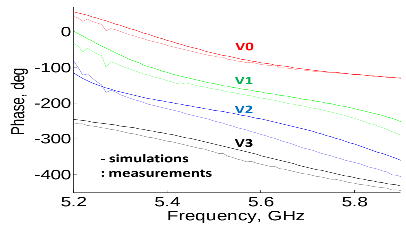
a



b



c



d

Fig. 2 *Comparison between simulations and measurements of the vertical phase configurations for all different horizontal configurations.*

a H0 *c* H2
b H1 *d* H3

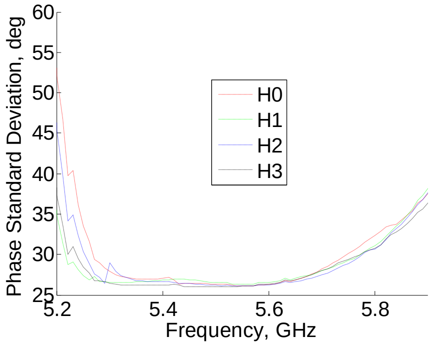


Fig. 3 *Phase standard deviation of the vertical polarization measured for all different horizontal configurations.*

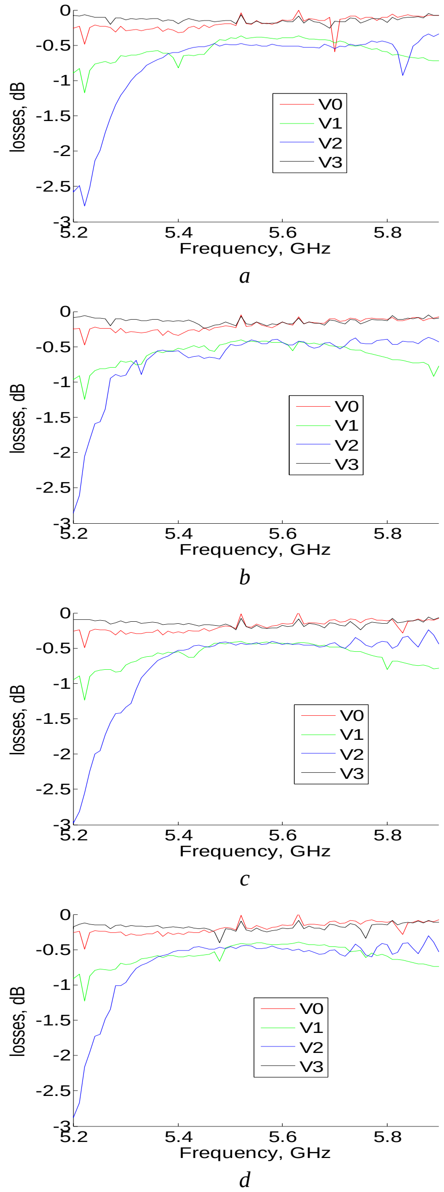


Fig. 4 *Measured losses for all different horizontal configurations.*

a H0 c H2

b H1 d H3

Conclusion: In this letter, a new dual linearly polarized phase-shifting cell for reflectarrays has been proposed. It uses two sets of slots loaded with a combination of fixed and variable capacitances to control the phase of the reflected wave. Measurements and simulations have demonstrated that the phase varies quite linearly with frequency and that the two polarizations are independent. The modification of the capacitance's (v) value is sufficient to provide 4 uniformly distributed phase states with low losses and low dispersion in the two polarizations on nearly 10% of bandwidth.

T. Makdissy, R. Gillard and E. Fourn (Université Européenne de Bretagne, INSA, IETR, UMR 6164, F-35708 Rennes, France)

E-mail: Tony.Makdissy@insa-rennes.fr

E. Girard and H. Legay (Thales Alenia Space, 26, Av. Jean Francois Champollion, 31037 Toulouse Cedex 1, France)

References

1. J. Encinar and J. Agustin Zornoza, "Broadband design of three-layer printed reflectarrays," IEEE Trans. Antennas Propag., vol. 51, no. 7, pp. 1662-1664, Jul. 2003

2. M. R. Chaharmir, J. Shaker, and H. Legay, "Broadband Design of a Single Layer Large Reflectarray Using Multi Cross Loop Elements," IEEE Trans. Antennas Propag., vol. 57, no. 10, pp. 3363–3366, Oct. 2009

3. T. Makdissy, R. Gillard, E. Fourn, E. Girard, H. Legay, "Triple-slot phase-shifting cell loaded with one variable capacitance for reflectarray applications," ELECTRONICS LETTERS, Vol. 48, no. 8, pp. 426-427, 12th April 2012

4. R. Pereira, R. Gillard, R. Sauleau, P. Potier, T. Dousset and X. Delestre, "Four-state dual polarisation unit-cells for reflectarray applications," ELECTRONICS LETTERS, Vol. 46, no. 11, 27th May 2010

5. T. Makdissy, R. Gillard, E. Fourn, E. Girard, H. Legay, "Triple-slot phase-shifting cell loaded with capacitances for reflectarray applications," European Conference on Antennas and Propagation EuCAP 2012, Prague, 26-30 March 2012

6. L. Boccia, G. Amendola, and G. Di Massa, "Performance improvement for a varactor-loaded reflectarray element," IEEE Trans. Antennas Propag., 2010, 58, (2), pp. 585-589